THE COMPARISON OF PERFORMANCE ISSUES ON HFC NETWORKS

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ABSTRACT

Hybrid Fiber Coaxial (HFC) network is widely used in residential network. The transmission time in HFC network is affected by upstream bandwidth, downstream bandwidth, and Cable Modem Termination System (CMTS) scheduling delay time. In this paper, we first discuss the effects of these three items to the HFC network performance. To improve the network performance, we try to find the most suitable item be altered.

1. INTRODUCTION

With the sustained development of HFC network in recent years, there were 13 millions of cable modems (CM) in North America in 2002 according to the statistics [1]. It was predicted that 86.5 million PC households and 42 million homes will have broadband Internet access before the end of 2007 in U.S. [1]. Data-Over-Cable Service Interface Specifications (DOCSIS) protocol [2] is the most popular standard in HFC network. It standardizes the operation of physical layer and media access layer in HFC network. In order to provide better services for users, the DOCSIS 1.0 was proposed in 1997, and then the DOCSIS 1.1 which supports the operation of Quality of Service (QoS) appeared in 1999. DOCSIS 2.0, proposed in 2001, supports Synchronous Code Division Multiple Access (S-CDMA) mode and makes the bandwidth of one upstream channel rising up to 30Mbps.

In this paper, we will analyze the transmission behavior of CM in DOCSIS protocol, and derive the theoretical lower bound of delay time and the theoretical upper bound of transfer rate. Based on the analysis, we identify the factor affects the delay time and transfer rate most significantly during the process of data transmission. According to the results, we propose some practicable improvements subsequently.

2. DOCSIS OPERATION

Detailed operations are illustrated in Figure 1 and listed as follows.

1. At time T_1, the CMTS transmits Bandwidth Allocation Map (MAP_1). CM receives MAP_1 at T_3 because of the round trip delay (RTD) time. The delay time of CM waiting for Contention Slot (CS) period is between T_3 and T_4.
2. At T_4, when CM enters CS period. CM needs to use Truncated Binary Exponential Backoff algorithm [2] to contend for CS between T_4 and T_5. At T_5, CM contends successfully and transmits request.
3. CMTS receives request sent from CM and starts scheduling from T_7 to T_8.
4. At T_8, CMTS finishes scheduling process and sends out MAP_2, then CM receives MAP_2 message at T_9.
5. CM waits for Data Slot (DS) period from T_{10} to T_{11}.
6. At T_{11}, CM starts transmitting data, and finishes at T_{13}. CMTS eventually receives all data at T_{14}.

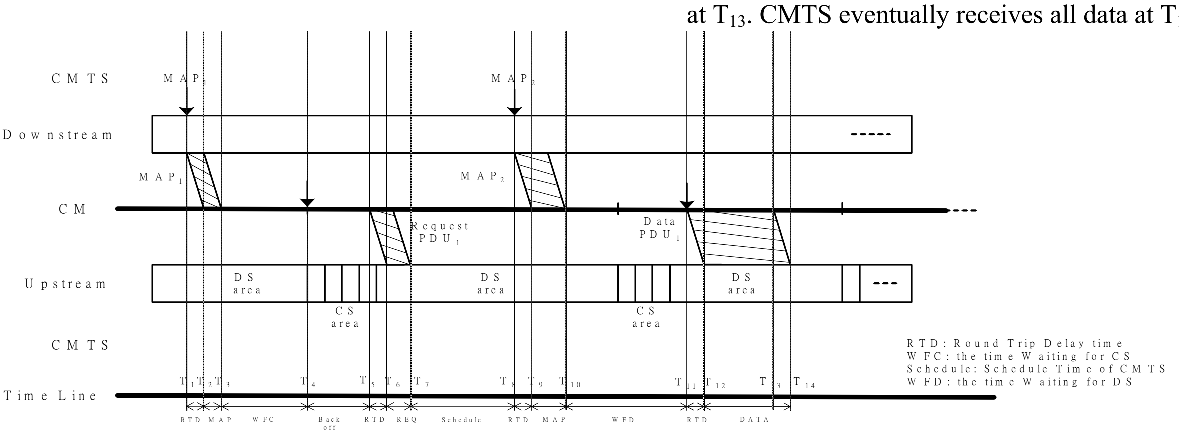

Figure 1. Operation of HFC network

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3. ANALYSIS

Now we can start the analysis according to Figure1. We focus on the values of delay lower limit (DLL) and transfer rate upper limit (TUL). The transfer rate means the amount of data transmitted per microsecond. Through DLL and TUL, we can find the effect of every transmission process to the delay time and transfer rate of the whole network. To obtain these two values, we need to define the achievable minimum delay (AMD) and the achievable maximum transfer rate (AMT) first. For obtaining AMD and AMT, we assume that the system operates at the best-case scenario. This means that our system operates on the following conditions. First, only one CM can transmit data in any transmission cycle. Second, channel is in ideal condition and no error happens. With these assumptions, we can define AMD and AMT as (1) and (2).

Because only one CM can transmit data at the moment, hence we assume the contention windows (*CW*) in the contention resolution algorithm is equal to zero for the above two equations. *WFC* and *WFD* represent the time waiting for CS and DS. *RTD* is the Round Trip Delay time. $T_{schedule}$ means the schedule time of CMTS. The data transmission delay time (T_{D_DATA}) is listed as follows.

$$T_{D\_DATA} = \frac{L_{PHY} + L_{H\_DATA} + L_{DATA}}{upstream\ \ bandwidth}$$

L_{PHY} is set as the transmission length of physical header. Physical header is included in every frame. L_{DATA} is the length of the transmitted data. L_{H_DATA} means the length to transfer data header. The MAP transmission delay time (T_{D_MAP}) is listed as follows.

$$T_{D\_MAP} = \frac{L_{PHY} + L_{MAP}}{downstream\ \ bandwidth}$$

L_{MAP} represents the length of MAP.

The request transmission delay time (T_{D_REQ}) is

$$T_{D\_REQ} = \frac{L_{PHY} + L_{REQ}}{upstream\ \ bandwidth}$$

L_{REQ} represents the length of request. It is easy to see the AMT is a monotone increasing function and AMD is a monotone decreasing function of bandwidth (both upstream and downstream). Next, we discuss the existence of DLL and TUL from three different points of view. They are upstream bandwidth, downstream bandwidth and the CMTS scheduling time. As the first two factors go to infinite and the last one nears zero, we come up with the following limit conditions.

First, we list the complete forms of the delay time and transfer rate in (3) and (4). Then, the existence of limit for DLL and TUL are analyzed from three different viewpoints.

3.1 Upstream bandwidth

From this aspect, we are sure that DLL and TUL exist. When the payload size is fixed and both downstream bandwidth and the CMTS scheduling time are given, we can obtain DLL and TUL as (5) and (6).

3.2 Downstream bandwidth

According to this item, we find that both DLL and TUL exist. When the payload size is fixed and both upstream bandwidth and the CMTS scheduling time are given, we can obtain DLL and TUL as (7) and (8).

3.3 CMTS scheduling time

Considering this scheduling time, we are sure that the DLL and TUL exist. When the payload size is fixed and both the upstream and downstream bandwidths are given, we can obtain DLL and TUL as (9) and (10).

$$AMD = WFC + CW + 3 \cdot RTD + T_{D\_REQ} + T_{schedule} + T_{D\_MAP} + WFD + T_{D\_DATA} \tag{1}$$

$$AMT = \frac{L_{DATA}}{WFC + CW + 3 \cdot RTD + T_{D\_REQ} + T_{schedule} + T_{D\_MAP} + WFD + T_{D\_DATA}} \tag{2}$$

$$DLL = WFC + CW + 3 \cdot RTD + \frac{L_{PHY} + L_{REQ}}{upstream\ bandwidth} + T_{schedule} + \frac{L_{PHY} + L_{MAP}}{downstream\ bandwidth} + WFD + \frac{L_{PHY} + L_{H\_DATA} + L_{DATA}}{upstream\ bandwidth} \tag{3}$$

$$TUL = \frac{L_{DATA}}{WFC + CW + 3 \cdot RTD + \frac{L_{PHY} + L_{REQ}}{upstream\ bandwidth} + T_{schedule} + \frac{L_{PHY} + L_{MAP}}{downstream\ bandwidth} + WFD + \frac{L_{PHY} + L_{H\_DATA} + L_{DATA}}{upstream\ bandwidth}} \tag{4}$$

$$DLL = WFC + CW + 3 \cdot RTD + T_{schedule} + \frac{L_{PHY} + L_{MAP}}{downstream \quad bandwidth} + WFD \tag{5}$$

$$TUL = \frac{L_{DATA}}{WFC + CW + 3 \cdot RTD + T_{schedule} + \frac{L_{PHY} + L_{MAP}}{downstream \quad bandwidth} + WFD} \tag{6}$$

$$DLL = WFC + CW + 3 \cdot RTD + \frac{2 \cdot L_{PHY} + L_{REQ} + L_{H\_DATA} + L_{DATA}}{upstream \quad bandwidth} + T_{schedule} + WFD \tag{7}$$

$$TUL = \frac{L_{DATA}}{WFC + CW + 3 \cdot RTD + \frac{2 \cdot L_{PHY} + L_{REQ} + L_{H\_DATA} + L_{DATA}}{upstream \quad bandwidth} + T_{schedule} + WFD} \tag{8}$$

$$DLL = WFC + CW + 3 \cdot RTD + \frac{2 \cdot L_{PHY} + L_{REQ} + L_{H\_DATA} + L_{DATA}}{upstream \quad bandwidth} + \frac{L_{PHY} + L_{MAP}}{downstream \quad bandwidth} + WFD \tag{9}$$

$$TUL = \frac{L_{DATA}}{WFC + CW + 3 \cdot RTD + \frac{L_{PHY} + L_{MAP}}{downstream \quad bandwidth} + WFD + \frac{2 \cdot L_{PHY} + L_{REQ} + L_{H\_DATA} + L_{DATA}}{upstream \quad bandwidth}} \tag{10}$$

4. NUMERICAL RESULTS

In the simulations, we assume extremely high upstream and downstream bandwidth and exceptionally short scheduling time to prove the DLL and TUL are correct.

4.1 Upstream bandwidth

Figure 2 shows the system delay time with different upstream bandwidth. We find that the system delay time decreases when the upstream bandwidth increases. Even when the upstream bandwidth is 50000Mbps, the system delay time is still lower than DLL. Figure 3 shows the system transfer rate with different upstream bandwidth. We can see that the system transfer rate increases as the upstream bandwidth increases. The system transfer rate still slower than TUL even the upstream bandwidth reaches 50000Mbps.

4.2 Downstream bandwidth

Figure 4 is the system delay time after increasing downstream bandwidth. It is obvious that the system delay time decreases when the downstream bandwidth increases. We also find that DLL does exist. The system transfer rate after increasing downstream bandwidth is shown in Figure 5 and we find that TUL does exist.

4.3 CMTS scheduling time

Figure 6 shows the system delay time after reducing CMTS scheduling time. As the scheduling time decreases, the system delay time also decreases. Figure 7 is the system transfer rate after lowering the CMTS scheduling time. As shown in the figure, the system transfer rate increases as the scheduling time decreases. From the above two figures, we are certain the existence of both DLL and TUL. system transfer rate increases as the scheduling time decreases. From the above two figures, we are certain the existence of both DLL and TUL.

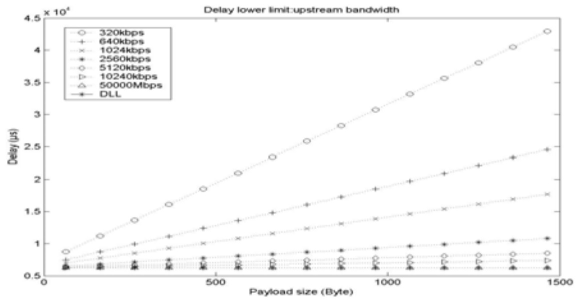

Figure 2. Delay time with different upstream bandwidth

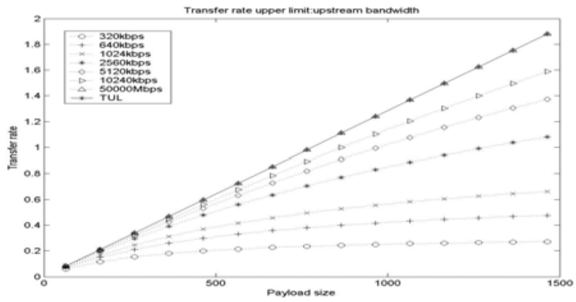

Figure 3. Transfer rate with different upstream bandwidth

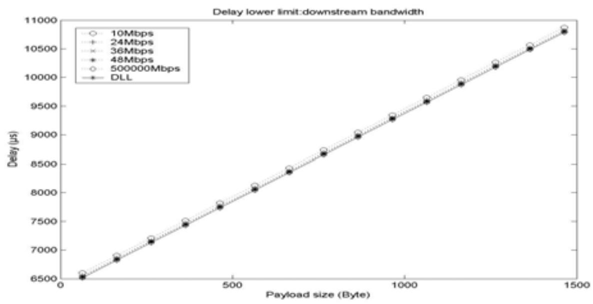

Figure 4. Delay time with different downstream bandwidth

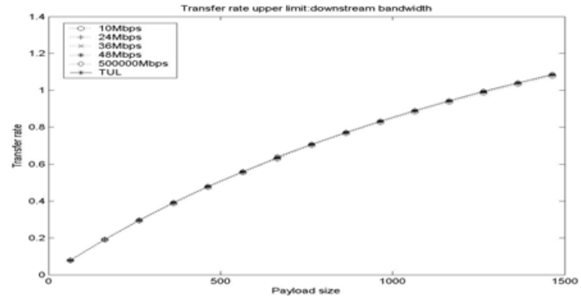

Figure 5. . Transfer rate with different downstream bandwidth

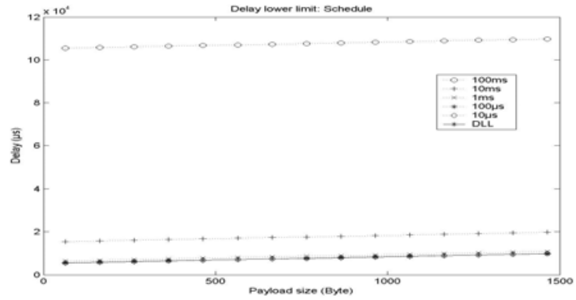

Figure 6. Delay time with different scheduling time

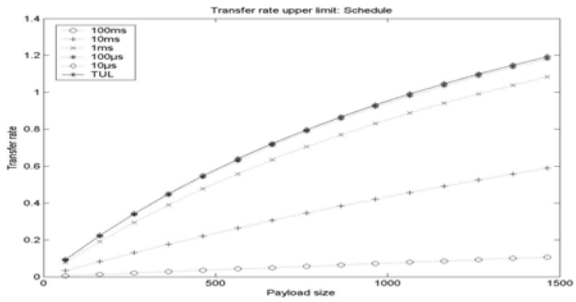

Figure 7. Transfer rate with different scheduling time

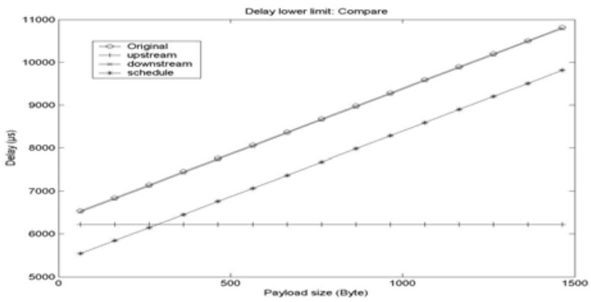

Figure 8. Delays time compare

4.4 Comparison

Figure 8 shows the system delay time after changing upstream bandwidth, downstream bandwidth, and CMTS scheduling time individually. The line marked with "original" stands for upstream bandwidth = 2560kbps, downstream bandwidth = 36Mbps, and scheduling time = 1ms. We find out that when payload size is small, the DLL resulted from changing the scheduling time is the

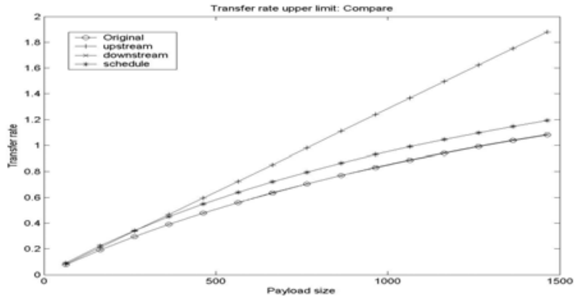

Figure 9. Transfer rate compare

best. But when the payload size is larger than 300bytes, altering the upstream bandwidth produces better result. Figure 9 shows the system transfer rate after changing upstream bandwidth, downstream bandwidth, and CMTS scheduling time. Obviously, changing downstream bandwidth is meaningless to transfer rate. The main reason is that only MAP is transferred through downstream bandwidth in the transmission cycle. From the results above, the best result comes from changing upstream bandwidth.

5. CONCLUSION

In this paper, we prove the existence of the DLL and TUL. The effects of upstream bandwidth, downstream bandwidth, and CMTS scheduling time to system delay time and transfer rate are also compared. We find out that changing the upstream bandwidth provides the most significant improvement to network performance.

6. REFERENCE

[1] Cable Television Laboratories, Inc., [Online] AVAILABLE :http://www.cablemodem.com

[2] Cable Television Laboratories, Inc., *Data-Over-Cable Service Interface Specifications, Radio Frequency Interface Specification*, SP-RFIv2.0-I06-040804, Aug. 2004.